



# Research on Large Deformation Control Measures of Surrounding Rock in Jointed and Altered Granite Stratum of High Ground Stress Tunnel

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**Abstract.** The large deformation of surrounding rock occurred frequently when Zangga tunnel passed through the high-stress jointed altered granite formation, and the deformation could not be controlled by the design scheme proposed in the initial stage of construction. Based on the monitoring results and geological data, this paper analyzed the deformation characteristics of jointed and altered granite in Zangga tunnel, and discussed the influencing factors of deformation. By means of a field test, the comprehensive control measures of surrounding rock deformation, which mainly includes adjusting the curvature of sidewall, combining long and short bolts and double-layer primary support, were studied. The results show that the deformation is characterized by large deformation value, fast deformation rate and long duration, and its tunnel convergence is greater than crown settlement. The influences of active fault on surrounding rock and alteration of surrounding rock are the internal causes of large deformation of the tunnel, while high ground stress is the external factor. The field test results show that the deformation value, rate and duration of surrounding rock can be controlled after the comprehensive control measures are adopted, and the construction efficiency is greatly improved.

**Keywords:** Altered granite stratum · High ground stress · Deformation characteristics · Double-layer primary support · Control measures

## 1 Introduction

The altered rock formed by the influence of magma intrusion is quite different from the original rock in mineral composition and structure. The altered rock usually has low density, strength and deformation modulus, and the rock mass is relatively broken. When the tunnel crosses the altered rock construction, problems such as large deformation, collapse and water gushing are prone to occur.

As a typical hard metamorphic rock, the density, strength and other physical and mechanical properties of altered granite are quite different from its original rock, and it is characterized by weak rock mass and poor self-stability. Scholars have carried out the following aspects of research: Fracture development and failure process of altered granite in uniaxial compression test (Coggan et al. 2007); Differences in physical and mechanical

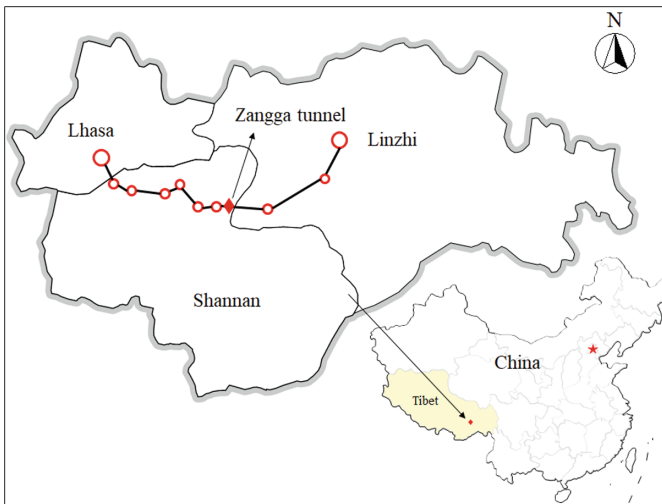
properties of granite under weathering and hydrothermal alteration (Khanlari and Naseri 2016); Hydrothermal alteration zone identification method and its relation to seismic activity (Meller and Kohl 2014). Previous studies mainly focus on the physical and mechanical properties of altered granite, but the study on the deformation characteristics of surrounding rock and supporting methods of the tunnel through altered granite is still not mature. Therefore, it is necessary to carry out relevant research.

Based on the monitoring results of jointed and altered granite stratum of Zangga tunnel, this paper analyzes the deformation characteristics of surrounding rock and discusses the influencing factors of deformation combining with geological and construction data. And the control measures of large deformation of surrounding rock is studied by field test.

## 2 Project Overview

### 2.1 Engineering Background

Zangga Tunnel is located between Nyenchenthanglha and Himalayas. The tunnel area is characterized by high mountains and deep valleys, rugged terrain, extreme harsh climate and typical mountain and canyon landforms. As one of the control projects of the Lhasa-Linzhi Railway, Zangga tunnel is a passenger and cargo collinear single-track tunnel with a total length of 8.755 km and a designed train speed of 160 km/h. The entrance mileage of Zangga tunnel is DK164+850, the exit mileage is DK173+605, the ground elevation is 3550–4400 m, and the maximum burial depth is about 778 m. The location and plane layout of Zangga tunnel is shown in Fig. 1.



**Fig. 1.** The location and plane layout of Zangga tunnel

### 2.2 Engineering Geology

The neotectonic movement in the tunnel area is strong, and the regional fault structure is extremely developed. The rock mass is relatively broken under the influence of regional

structure, and is affected by magma intrusion for many times. The local rock mass alteration characteristics are obvious. The DK168+805–DK169+140 section of the tunnel mainly passes through weakly weathered granite ( $E_2R$ ). The rock mass has developed joints and fractures with a steep dip Angle. The local rock mass has a low strength under the influence of alteration and poor self-stability ability. The DK168+805–DK169+140 section of the tunnel mainly passes through weakly weathered granite ( $E_2R$ ). The rock mass has developed joints and fractures with a steep dip Angle. The local rock mass has a low strength under the influence of alteration and poor self-stability ability. The groundwater in the rock mass in this section is moderately – weakly developed, and there is angular unconformity contact among the rock masses. The longitudinal section diagram of typical tunnel sections is shown in Fig. 2.

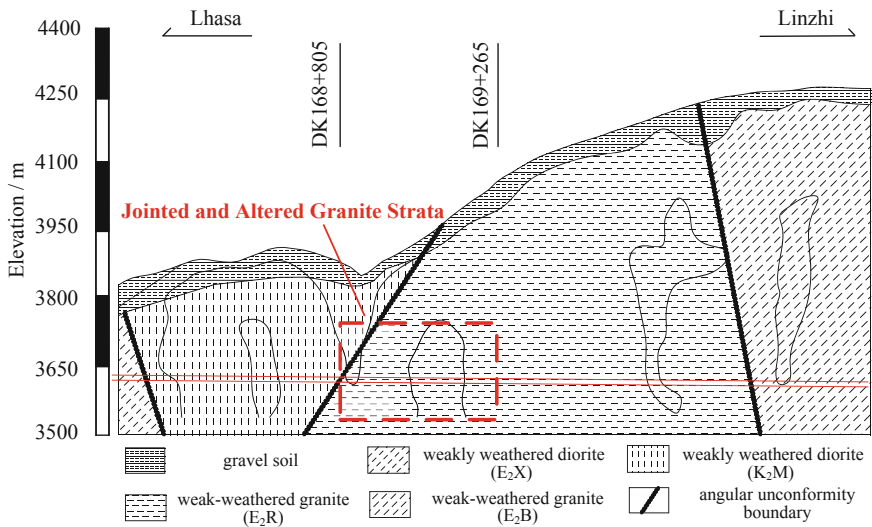


Fig. 2. A longitudinal section of a typical section in Zangga tunnel area

By measuring the ground stress of the deep hole in the tunnel area, it can be seen that the average ratio of the maximum horizontal principal stress and vertical stress is 1.29 and the maximum value is 1.76. This indicates that the ground stress in the tunnel area is mainly tectonic stress, and its direction is  $N6^{\circ}W-N7^{\circ}E$ . And the maximum horizontal ground stress is 17.72 MPa.

### 2.3 Situation of Tunnel Construction

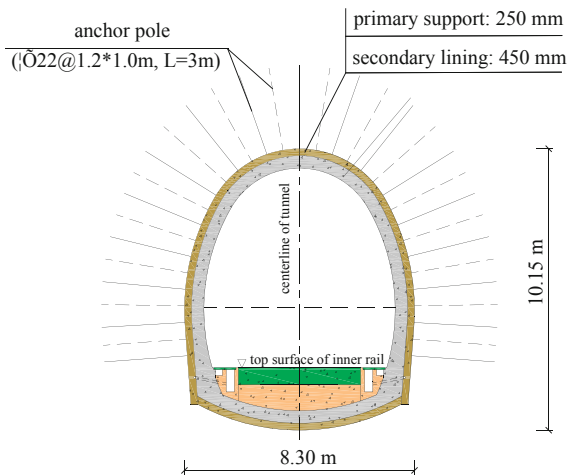
On March 13, 2017, construction of the tunnel began at DK169+000, where the tunnel intersects with the inclined shaft. The surrounding rocks revealed by excavation are jointed and altered granite, as shown in Fig. 3. The rock mass has developed joints and fractures with a steep dip Angle, and the structural plane is infected with iron and manganese, with visible scratches and the development characteristics of fault gouges.

The rock mass has low strength and poor integrity, the partial rock mass is easily broken by hand, and surrounding rock has a poor self-stability ability.



**Fig. 3.** Jointed and altered granite

The surrounding rock grade and the original support design scheme were changed on-site because the surrounding rock was exposed to be broken. DK169+025–DK169+140 section of the surrounding rock grade by III level changed for V level, and the construction method by entire section method changed to bench method. After design change, the segment most areas supporting structure adopted  $V_c$  composite lining, which section height was 10.15 m and width was 8.30 m, as shown in Fig. 4. In the primary support, anchor rods with a length of 3 m and a diameter of 22 mm are set at the arch and sidewall positions, with a circular spacing of 1.2 m and a longitudinal spacing of 1.0 m. In addition, the spacing of section steel frames is 0.8 m, and the thickness of C25 shotcrete is 250 mm. The reserved deformation value of tunnel primary support is 100 mm. And the secondary lining is made of 450 mm thick C35 reinforced concrete.



**Fig. 4.** Section view of  $V_c$  composite lining structure

The construction sequence of DK169+025–DK169+140 are as follows: ① The advanced reinforcement of the arch of the tunnel face. ② Excavate and support the upper bench with a height of 4.4 m and a length of 10 to 20 m. ③ The left and right sides of the bottom bench are staggered apart from the excavation and support, the bottom bench is 4.2 m high, and each bench is 3–8 m long. ④ Excavate and support the tunnel invert. ⑤ Complete the secondary lining according to the monitoring measurement results. Construction sequence of bench method is shown in Fig. 5.

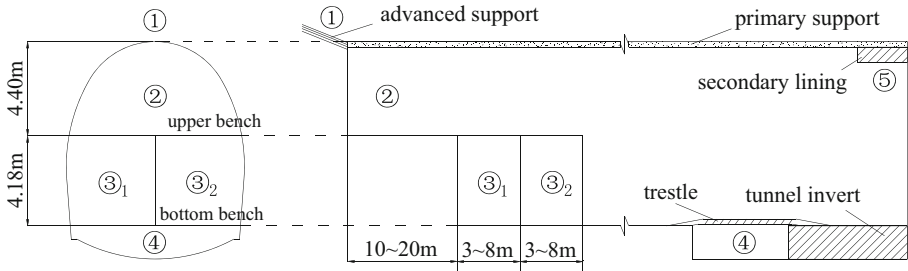


Fig. 5. Construction sequence of bench method

With the progress of construction, large deformation of surrounding rock appeared in different degrees in the tunnel area. Problems such as bending fracture of steel arch, cracking and dropping of jetted concrete, and deformation limit of primary support (shown in Fig. 6) occurred frequently. The maximum crack width of jetted concrete was 26 mm. For these problems, the construction unit removed and replaced the primary support, and these measures seriously affected the construction period. The deformation control measures of surrounding rocks suitable for this section needed to be further studied.

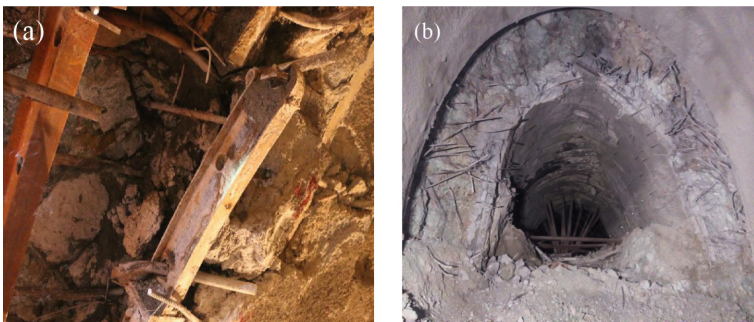


Fig. 6. Typical pictures of primary support damage: (a) fracture of steel arch; (b) schematic diagram of primary support deformation

### 3 Deformation Characteristics of Surrounding Rock and Its Influencing Factors

#### 3.1 Overall Deformation of Large Deformation Section

Section DK169+025–DK169+140 is taken as the large deformation section for analysis. According to the data obtained from statistical monitoring, the surrounding rock deformation of this section is shown in Fig. 7. The measured point of tunnel convergence is located near the junction of upper and bottom bench, and the negative value represents the inward deformation of the tunnel. The crown settlement of this section is from 71 to 656 mm. The maximum daily settlement, which is located at DK169+122, is 35 mm; The tunnel convergence is from 245.3 to 3032 mm, and the maximum daily tunnel convergence, located at the junction of upper and bottom bench of DK169+090, is 128 mm. The maximum crown settlement and tunnel convergent deformation appear at section DK169+122. The tunnel convergent deformation of DK169+025–DK169+140 section is obviously greater than the crown settlement. Most of the section deformation exceeded the reserved deformation value (100 mm), and the primary support deformation seriously exceeds the limit value. Results show that the  $V_c$  composite lining structure on the formation adaptability is poorer, and it cannot control the deformation of the surrounding rock.

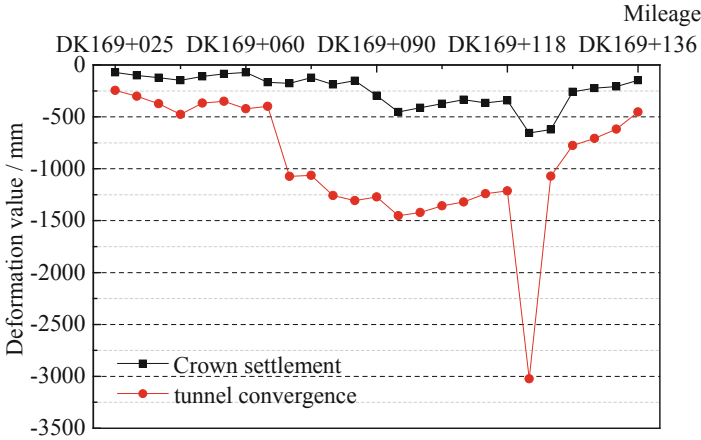


Fig. 7. Cumulative deformation of surrounding rock at the section of DK169+025–DK169+140

#### 3.2 Deformation Characteristics of Surrounding Rock with Typical Section

Bench method was used for the DK169+090 section construction, and supporting structure adopted  $V_c$  composite lining. The tunnel deformation and rate curves are shown in Fig. 8.

Within 48 days, the cumulative crown settlement value of this section is 295 mm, and the cumulative tunnel convergence value is 1272 mm. The deformation of surrounding

rock is divided into the acceleration stage and development stage during the whole monitoring period, and the deformation keeps increasing.

After upper bench excavation, surrounding rock deformation increased rapidly, arch crown settlement was 13 mm within 1d excavation, and tunnel convergence was 90 mm. Subsequently, the crown settlement deformation kept a steady increase at a rate of 10–13 mm/d. After a short decrease, the tunnel convergence rate increased to a peak of 128 mm/d at 5d of excavation. After five days, the deformation rate of surrounding rock gradually decreased. Before excavation on the left side of the bottom bench, the crown settlement value reached 133 mm, accounting for 33.71% of the total deformation. The tunnel convergence value reached 704 mm, accounting for 55.33% of the total deformation. The deformation rate fluctuated in this stage.

After excavation on the left side of the bottom bench, the deformation rate of surrounding rock slowed down to a certain extent, but the deformation continues to increase at a steady rate. There was no obvious convergence trend in surrounding rock deformation after supporting tunnel invert.

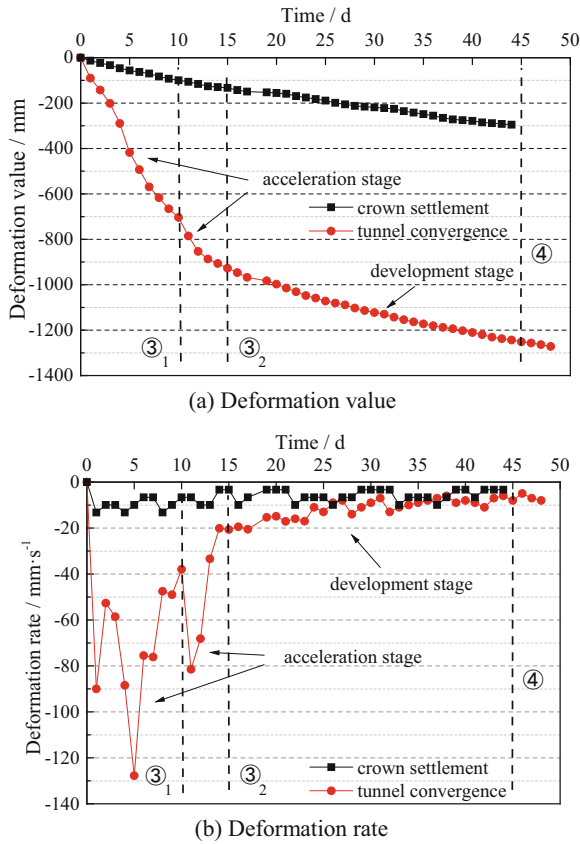


Fig. 8. The tunnel deformation and rate curves at the section DK169+090

### 3.3 Deformation Characteristics of Surrounding Rock

Combined with the deformation of typical sections, it can be seen that during the construction of section DK169+025–DK169+140, the surrounding rocks show the following deformation characteristics: ① The deformation of surrounding rock is characterized by large value and fast deformation rate, and the tunnel convergent deformation is obviously greater than the crown settlement deformation; ② The deformation of surrounding rock is divided into acceleration stage and development stage. After the support structure is closed, the deformation rate of surrounding rock does not decrease significantly and the deformation of surrounding rock continues to increase. ③ Construction has a great influence on the deformation of surrounding rock. During the excavation of upper and bottom bench, the deformation rate fluctuation of surrounding rock will occur, which has a great influence on the deformation value of surrounding rock. ④ The deformation of surrounding rock lasts for a long time. In 45 days, the deformation of surrounding rock shows no obvious convergence trend, and the deformation still keeps a slow growth.

### 3.4 Influencing Factors of Surrounding Rock Deformation

Based on the comprehensive analysis of surrounding rock deformation monitoring results and geological data, it is found that the main factors affecting surrounding rock deformation are as follows:

#### (1) Geological reasons

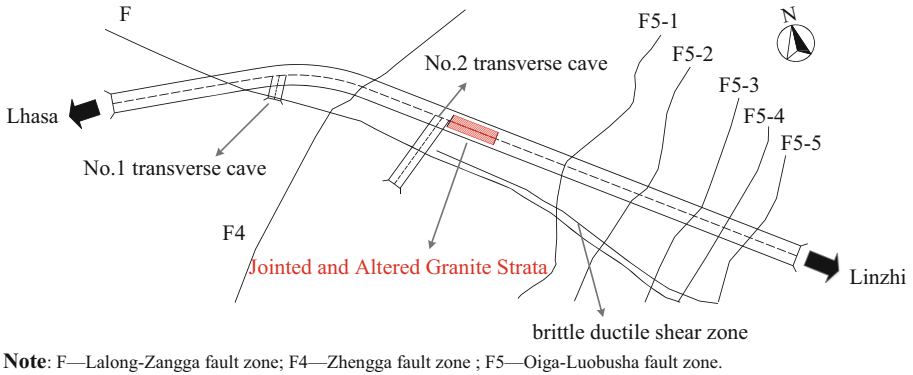
Fault zone distribution diagram of Zangga tunnel is shown in Fig. 9. The F5-2 fault in the eastern margin of Oiga Basin is a seismogenic fault of the Sangri 7.0-magnitude earthquake in 1915, with frequent strong seismic activity (Q<sub>4</sub> active fault). The tunnel area is located in the fault-affected zone of the eastern margin of The Oiga Graben. Under the influence of geological structure, the folds, joints and fractures in the tunnel area are extremely developed, with poor interlayer bonding and separation, and the strength of the structural plane is in the residual state. The unconformity of the Angle between rock stratum makes the integrity of rock mass seriously damaged and causes the rock mass structure to be loose and broken.

In addition, the rock mass is affected by multiple magmatic intrusions, and the granite in the large deformation section shows obvious alteration characteristics. The rock mass is a cataclastic dispersion structure with low strength, and the rock block is easily broken by hand. The whole self-stabilization ability of surrounding rock is low, and the surrounding rock is easy to be deformed after excavation.

#### (2) High ground stress

Through the ground stress tests, within the test range of 604.45m, by hydraulic fracturing technique, the maximum horizontal ground stress of the rock mass is 17.72 MPa, with a maximum ratio of 1.76 to the vertical stress. There is large structural stress in the rock mass with a dominant direction of N9°W–N7°E. Due to the low strength of altered granite in the large deformation section of Zangga tunnel, the surrounding rock is prone to deformation under the influence of high ground stress.





**Fig. 9.** Fault zone distribution diagram of Zangga tunnel

(3) Other factors

Scholars find that the shape of the section plays a certain role in controlling the convergent deformation of surrounding rocks. The closer the cross-section shape is to the circle, the stronger the resistance to tunnel convergent deformation is. However, Zangga tunnel is a single-line railway tunnel, which high-span ratio of the excavated section is relatively large (about 1.22) and the curvature of the sidewall is small. The shape of this section has no obvious advantage in the control of convergent deformation. Therefore, under the condition of unfavorable section shape, large tunnel convergent deformation is easy to occur after tunnel excavation due to the influence of high tectonic stress. In addition, groundwater, bench length and impact of construction are also factors that cause large deformation.

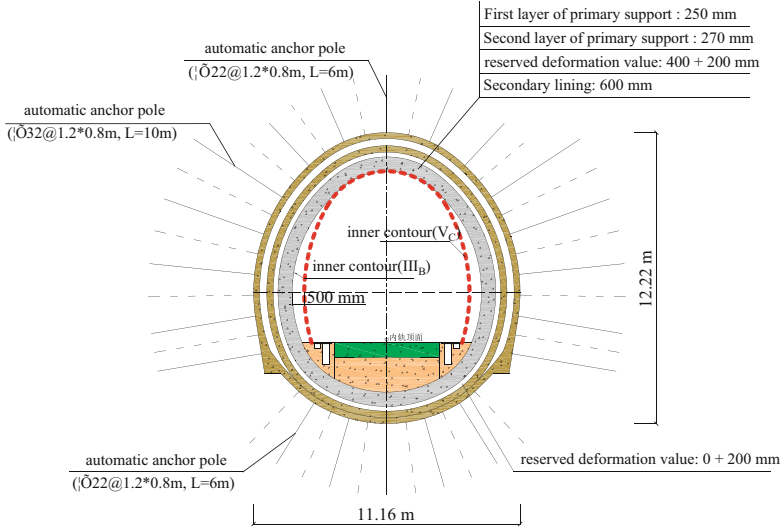
## 4 Control Measures for Large Deformation of Surrounding Rock

Through the above analysis, the deformation characteristics of surrounding rock and the influencing factors of the jointed and altered granite stratum of Zangga tunnel section are clarified. Based on the concept of “combination of release and resistance” control measures for large deformation of soft rock tunnel, the comprehensive control measures for surrounding rock deformation are put forward, including: Adjusting the curvature of sidewall; Adopting advance reinforcement and double-layer primary support; Increasing the reserved deformation; Setting up long anchor rod. Additional auxiliary construction measures such as temporary invert and anchor pipe are also very important control measures. The field test section of surrounding rock is given priority to with V level of surrounding rock, joint and fissure development. The rock mass is of fragmentation structure with low strength and easy to disintegrate in water. There is no significant difference between DK169+025–DK169+140.

**4.1 Control Measures of the Field Test Section**

(1) Support method

Compare with  $V_c$  composite lining structure,  $III_B$  lining structure (shown in Fig. 10), applied in the field test section, adjusts the sidewall curvature (lateral wall arch camber increased 500 mm) and adopts a more powerful supporting measures in advance reinforcement. The primary support is strengthened from one layer to the double layer, which improves the stiffness of the primary support. The reserved deformation value of primary support is increased. The reserved deformation amount of the first layer is 400 mm (The value at the invert is 0 mm), and that of the second layer is 200 mm. Moreover,  $III_B$  lining structure strengthened the anchor design parameter, also added some auxiliary construction measures such as the temporary inverted arch and lock foot anchor pipe. Support parameters of the field test section are shown in Table 1.



**Fig. 10.** Section diagram of lining structure of type  $III_B$  test section

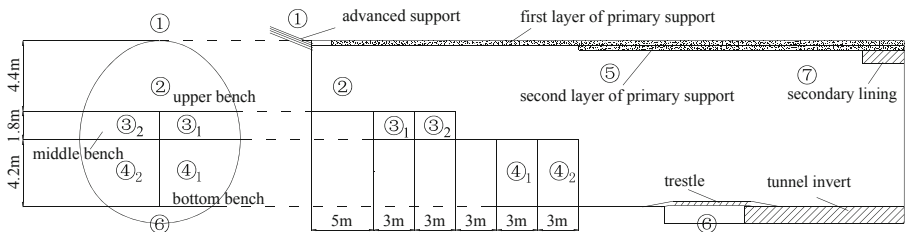
(2) Excavation method

The field test section is constructed by three-bench method, and the length of the bench is strictly controlled. Specific construction steps are as follows: ① The advanced reinforcement of the arch of the tunnel face. ② Upper bench excavation, followed by the first layer of primary support. The excavation height of the upper bench is 4.4 m. ③ Excavate and support on the right side of the middle bench, with the excavation height of 1.8 m and 5 m from the upper bench; The left side of the middle bench shall be excavated and supported, 3 m from the right side. ④ Excavate and support on the right side of the bottom bench, and the excavation height is 4.2 m, 3 m from the left side of the middle bench; Excavation and support shall be carried out on the left side of the bottom bench, 3 m from the right side. ⑤ In

**Table 1.** Support parameters of the field test section.

Mileage	Advanced reinforcement measures	Support measures
DK169+140–DK169+200	Pipe shed ( $\Phi 89$ mm@6.6 * 0.4 m, L = 10 m; 29 rings per ring) Or small pipe ( $\Phi 42$ mm@1.8 * 0.4 m, L = 3.5 m, 29 rings per ring)	It is shown in Fig. 10
DK169+200–DK169+263	Except small pipe ( $\Phi 42$ mm@2.4 * 0.4 m, L = 3.5 m, 29 rings per ring), the other advance support parameters are the same as the above contents	Based on the design parameters in Fig. 10, the following contents are added: the I20b temporary invert with a distance of 1.2 m at the upper bench, and the four anchor pipes with a length of 4 m and a diameter of 42 mm on the steel frame at the arch foot on the two sides of the middle bench

time use the self-feeding anchor ( $\Phi 32$ ). After the primary support on the left and right sides of the bottom bench is completed, the second layer of primary support is applied on the basis of the first layer of primary support at the arch and the sidewall. ⑥ According to the monitoring and measurement results, determine the best time for the secondary lining and apply the secondary lining. Construction sequence of the three-bench method is shown in Fig. 11.

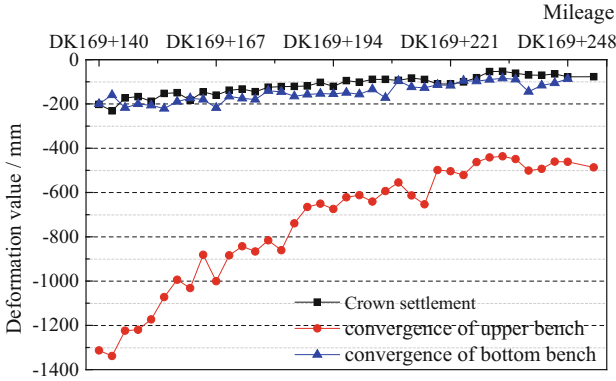


**Fig. 11.** Construction sequence of three-bench method

### 4.2 Deformation of Surrounding Rock in the Field Test Section

After adopting control measures such as double-layer support, the cumulative deformation curve of surrounding rock in the field test section DK169+140–DK169+263 is statistically obtained, as shown in Fig. 12. The statistical data of surrounding rock deformation in large deformation section and test section are shown in Table 2.

It can be seen from the figure and the table that the deformation of surrounding rocks in the test section is well controlled. The maximum crown settlement in the test



**Fig. 12.** Cumulative deformation of surrounding rock at the section of DK169+140–DK169+263

**Table 2.** Statistical data of large deformation section and test section

Mileage	Crown settlement/mm		Upper bench convergence/mm		Bottom bench convergence/mm		Reserved deformation value/mm	Deformation duration/d
	Average	Maximum	Average	Maximum	Average	Maximum		
DK169+025–DK169+140	248.3	656	942.7	3 023.1			30–100	No convergence trend (within 45d)
DK169+140–DK169+200	146.5	231.1	927.9	1 338.4	172.6	220.8	400+200	60–75
DK169+200–DK169+263	82.09	110.4	521.52	653.5	114.63	144.5	400+200	35–50

section is 231.1 mm and located in section DK169+143. The maximum value of tunnel convergence is 1338.4 mm, located at the upper bench on DK169+143 section, and the overall deformation value of the field test section is less than that of the large deformation section. The control effect can be reflected from the following aspects.

- (1) The deformation value of surrounding rock is controlled. After adjusting the curvature of the sidewall and adopting the double-layer primary support structure, the surrounding rock deformation value of the test section is lower than that of the large deformation section, and the deformation value is basically within the safe range.
- (2) Deformation rate of surrounding rock is significantly reduced. In the 3–5 days after the excavation of the upper bench, the average deformation rate of the upper bench convergence in the surrounding rock of the large deformation section is over 50 mm/d, while the corresponding deformation rates in the test section DK169+140–DK169+200 and DK169+200–DK169+263 are within 30–50 mm/d and 10–30 mm/d respectively. The deformation rate is well controlled.

- (3) The deformation duration of surrounding rock is shortened. The deformation of the surrounding rock in the large deformation section did not show a convergence trend within about 45 days, while the deformation of the surrounding rock in the test section was stable within about 35–75 days, and the deformation duration was significantly shortened.
- (4) The control effect of DK169+200–DK169+263 section is better than that of DK169+140–DK169+200 section. Through the comparison of deformation data, it can be seen that the deformation duration of section DK169+200–DK169+263 is relatively short after the addition of temporary invert and anchor pipe. At the same time, the average cumulative convergent deformation rate of the upper bench in each construction stage of this section is only 48.72%, 57.14% and 77.54% of the DK169+140–DK169+200 sections, making its cumulative deformation value small. The additional auxiliary measures such as the temporary invert and anchor pipe on the upper bench have a positive effect on the deformation control of the formation.

### 4.3 Application Effect

The large deformation section of DK169+025–DK169+140 started construction on April 7, 2017, and completed invert excavation on January 13, 2018 (281d). Since most of the primary support deformation exceeded the limit value, the construction unit removed and replaced it, which consumed a total of 403 days. The excavation of the test section DK169+140–DK169+263 takes a total of 217 days, and the total construction time of the whole section is 248 days. The comparison shows that the tunnel construction efficiency is obviously improved.

At present, Zangga tunnel has been successfully completed. After the comprehensive control measures of surrounding rock deformation have been adopted, no abnormal phenomena have appeared in the construction process of the test section and subsequent such stratum, and the construction effect is good. It can be seen that the comprehensive control measures of surrounding rock deformation, which mainly include adjusting the curvature of sidewall, the combination of long and short bolts and double-layer primary support, have a good effect on the deformation control of surrounding rock.

## 5 Conclusions

When Zangga tunnel passed through the jointed and altered granite stratum, the surrounding rock appeared large deformation phenomenon, and the primary support structure was seriously damaged. The support design has insufficient adaptability to the stratum. Based on the above deformation results of the surrounding rock, this paper analyzed the deformation characteristics of the surrounding rock in the jointed and altered granite stratum, discussed the influencing factors of the surrounding rock deformation, and studied the deformation control measures through field tests. The main conclusions are as follows:

- (1) During the construction of the jointed and altered granite stratum with high ground stress tunnel, the surrounding rocks show the characteristics of large magnitude

and fast speed, and the tunnel convergent deformation is greater than the crown settlement. The deformation of surrounding rock is divided into acceleration and development stages. The deformation rate does not decrease significantly after the enclosing structure is closed and formed, and the deformation of surrounding rock continues to increase. The original design cannot control the deformation.

- (2) The large deformation of surrounding rock is caused by geological reasons, high ground stress and other reasons. Among them, the influence of active fault on surrounding rock and alteration of surrounding rock are the internal causes of large deformation of tunnel, while high ground stress is the external factor. In addition, the influence of section shape, excessively long construction bench and construction on surrounding rock deformation cannot be ignored.
- (3) Combined with the characteristics and influencing factors of surrounding rock deformation, the comprehensive control measures of surrounding rock deformation are put forward, including adjusting the curvature of surrounding rock, combining long and short bolt and double-layer main support. The field application results show that the deformation value, rate and duration of surrounding rock can be controlled, the construction effect is good, and the construction efficiency is greatly improved. The research can provide reference for subsequent construction and similar projects.

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